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Introduction

Mr. Chairman and members of the Committee, it is a pleasure and an honor for me to testify to you today regarding the National Nanotechnology Initiative (NNI) and general competitive position of United States in nanotechnology. My name is Floyd Kvamme and I am a Partner at Kleiner Perkins Caufield & Byers, a high technology venture capital firm located in Silicon Valley. That is my full time occupation. I was also honored to be asked, and accepted an invitation, by President George W. Bush in 2001 to co-chair his science and technology advisory group, the President's Council of Advisors on Science and Technology (PCAST). The PCAST is a group of non-government advisors comprising some two dozen senior representatives, appointed by the President, and drawn from industry, education, and research institutions, and other nongovernmental organizations. The President's Science Advisor, the Director of the Office of Science and Technology Policy (OSTP) Jack Marburger, co-chairs the PCAST along with me.

Potential of Nanotechnology

"Nanotechnology" touches upon a broad array of disciplines, including chemistry, biology, physics, computational science, and engineering. And like information technology, nanotechnology has the potential to impact virtually every industry, from aerospace and energy to healthcare and agriculture. Based on the ability to see, measure, and manipulate matter at the scale of atoms and molecules, nanotechnology was born, in many ways, with the advent of atomic force microscopy in the mid-1980s. Today many industries such as those based on semiconductors and chemicals already are creating products with enhanced performance based on components and materials with nanosized features.

Nanotechnology today reminds me very much of the early days of the semiconductor industry. The new interdisciplinary relationships being forged and the sense of excitement over future possibilities are very reminiscent of that earlier period.

As with semiconductors, future application of nanotechnology based on evolving research could have significant impact throughout the world. Examples where nanotechnology has the potential to vastly improve standards of living in industrialized and developing nations include: medical applications, clean water, and energy. In our

report, we highlight some key research in these areas. In medical applications, for example, nanotechnology has made possible the creation of a synthetic bone replacement material that is highly biocompatible and allows bones to heal faster and more completely than the materials that are used today. In the area of energy efficiency, researchers at Sandia Laboratories have demonstrated a light source that mixes different sized "quantum dots" to create high-efficiency white "light emitting diodes" that use about one-tenth as much energy as an incandescent bulb and that could reduce by more than half the amount of electricity used for lighting nationwide. Finally, researchers at Lawrence Livermore National Laboratory are nanoengineering membrane systems that can target and remove contaminants in water, while reducing treatment costs by at least half compared to conventional technologies. Low-cost clean water technologies have obvious application in remediation of contaminated groundwater and treating industrial waste, as well as significant potential to help improve public health in developing nations.

The early recognition of the broad range of useful and powerful nanotechnology applications led to the formal establishment of a National Nanotechnology Initiative (NNI) in Fiscal Year (FY) 2001. Due to its potential to promote innovation and economic benefits, to address the needs of the Federal agencies, as well as to strengthen the position of the United States as a leader in science and technology, the Administration has identified nanotechnology as a top research and development (R&D) priority for the past several years.

History of PCAST's Involvement with Nanotechnology

The history of PCAST's involvement with the NNI extends back to 1999 when the analogous body under the previous Administration supported a proposal for establishing an interagency nanotechnology initiative. In their letter to the President, they included a recommendation that "the progress toward NNI goals be monitored annually by an appropriate external body of experts, such as the National Research Council." In part based on this recommendation, the National Research Council (NRC) was commissioned to do a study of the NNI, which was released in 2002. The first of that study's ten recommendations was that OSTP establish an independent standing nanoscience and nanotechnology advisory board to provide advice to the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee (the interagency body that coordinates the NNI) on policy, strategy, goals, and management.

The President's FY 2004 Budget, released in February 2003, acknowledged the NRC's recommendation for external review, and directed PCAST to conduct an assessment and provide advice regarding the strategic direction of the NNI program. PCAST began this task shortly thereafter.

The 21st Century Nanotechnology Research and Development (R&D) Act

As PCAST was undertaking its review of the NNI, this Subcommittee and its Senate counterpart were also in the midst of creating new legislation that would make statutory the activities and organization of the NNI, along with periodic reviews and other aspects of this vital R&D effort. The requirement for an ongoing outside advisory panel was ratified by Congress in the 21st Century Nanotechnology Research and Development Act of 2003 (Public Law 108-153; hereafter referred to as "the Act"), which called for the President to establish or designate a National Nanotechnology Advisory Panel (NNAP). PCAST's role was reaffirmed when, in July 2004 by Executive Order, the President formally designated PCAST to fulfill the duties of the NNAP. The order amended the original Executive Order commissioning PCAST, thus establishing that nanotechnology should be included in the formal PCAST charter.

As detailed by Congress in Section 4, the Act calls upon the NNAP to assess the national nanotechnology program in the following areas:

- Trends and developments in nanotechnology
- Progress in implementing the program
- The need to revise the program
- Balance among the component areas of the program, including funding levels
- Whether program component areas, priorities, and technical goals developed by the NSET Subcommittee are helping to maintain US leadership
- Management, coordination, implementation, and activities of the program
- Whether social, ethical, legal, environmental, and workforce concerns are adequately addressed by the program

The Act requires the NNAP to report on its assessments and to make recommendations for ways to improve the program at least every two years. The first such report provided by PCAST in its role as the NNAP is now complete and was delivered to this Subcommittee at the hearing that was held on May 18th. The remainder of my testimony will focus on this report and the observations and recommendations contained therein. Also, because PCAST was designated as the statutorily mandated NNAP, from this point forward in my testimony I will refer to PCAST as the NNAP.

Technical Advisory Group

Before getting into the specifics of the report, I'd like to highlight a resource that our panel relied on during the course of the review in order to augment the NNAP's expertise in managing large R&D programs with more specific nanotechnology technical expertise. Early in our review, the NNAP identified a Technical Advisory Group (TAG) comprising approximately 45 nanotechnology experts who represent diverse disciplines and sectors across academia and industry. The TAG is a knowledgeable resource, providing input and feedback with a more technical perspective. The NNAP called upon its TAG on several occasions for broader expert opinions on various topics. Two particular areas where the TAG was very helpful were in reviewing and providing

feedback on the NNI Strategic Plan and in helping to illuminate and rationalize for the NNAP some of the key opportunities in nanotechnology research over the short, medium and long term. Input from the TAG has been considered and is represented in the report you have before you today.

NNAP Report

The approach we took during our first assessment of the NNI was to ask some basic questions that encompass the requirements of the Act and that we perceived to be the most pressing questions the President, the Congress and the American public wanted answers to. These were:

- **Where do we stand?** In other words, how does our competitive position in nanotechnology R&D stack up relative to other countries?
- **Is this money well spent and the program well managed?** This encompasses the general request for an external assessment of the NNI.
- **Are we addressing societal concerns and potential risks?** Responding to specific Congressional and public concerns, are we paying close enough attention to environmental, health and safety risks and other societal issues?
- **How can we do better?** What does the NNAP recommend that will help the U.S. strengthen its nanotechnology effort?

I will summarize our assessment and recommendations, and recommend to the committee our full report for a more thorough review of these issues.

Where do we stand?

In attempting to compare the strength of the U.S. nanotechnology effort internationally, the NNAP reviewed a number of metrics that our members felt were appropriate for assessing the competitive position of the U.S in this new technology area where research and technology discoveries in many cases have yet to reach the marketplace. We looked at available data for levels of international R&D investment by governments (including federal, regional, state, and local), as well as private corporations and venture capital firms. We also surveyed data on patent and publication trends to assess commercial interest and strength of research findings among various countries that are active in nanotechnology.

The data surveyed indicate that, today, the United States is the leader in nanotechnology R&D. The approximately $1 billion annual Federal Government funding for nanotechnology R&D is roughly one-quarter of the current global investment by all nations. Total annual U.S. R&D spending – including Federal, State, and private funding -- now stands at approximately $3 billion, one-third of the approximately $9 billion in total worldwide spending by the public and private sectors. It is noteworthy that State, local and regional governments have been particularly active in promoting nanotechnology development, investing $400 million in 2004 according to one

estimate.[1] In addition, the United States leads in the number of start-up companies based on nanotechnology, and in research output as measured by patents and publications.

However, the data also show that other countries are aggressively chasing this leadership position, both in terms of ramping up coordinated national programs – many of which are modeled directly on the NNI -- as well as in focusing investments to areas of existing national economic strength. For example, many of the Asian countries are investing heavily in nanoelectronics. Further, the U.S. lead in publications and patents appears to be slipping. Increased international activity is resulting in increased competitive pressure from other nations and, in the opinion of the NNAP, an increased urgency that the U.S. continues its focus on nanotechnology R&D excellence.

Is this money well spent and the program well managed?

Chapter 2 of the report provides an assessment of the NNI program and its accomplishments. The NNAP also evaluated the Administration's recently released Strategic Plan and the mechanisms in place to manage the program. The NNAP concludes that the money the United States is investing in nanotechnology is money very well spent, and that continued robust funding is important for the Nation's long-term economic well-being and national security.

Nanotechnology holds tremendous potential for stimulating innovation and thereby enabling or maintaining U.S. leadership in industries that span all sectors. The NNAP concludes that the strategic focus of the NNI on expanding knowledge of nanoscale phenomena and on discovery of nanoscale and nanostructured materials, devices, and systems, along with building an infrastructure to support such studies, has been both appropriate and wise. The NNI has accomplished much already—advancing foundational knowledge, promoting technology transfer for commercial and public benefit, developing an infrastructure of user facilities and instrumentation, and taking steps to address societal concerns—and we believe the economic pay-offs over the long term should be substantial.

The NNAP commends the NNI in particular for making the long-term commitment to nanotechnology R&D through the establishment of a geographically distributed suite of centers of excellence and broadly available user facilities. Largely university-based, the centers provide education of skilled scientists and engineers as well as serving as focal points of multidisciplinary R&D and, hopefully, new economic opportunities that are geographically dispersed. User facilities, such as the five Department of Energy Nanoscale Science Research Centers, provide access for all researchers to state-of-the-art equipment and expertise for advanced nanotechnology R&D. Staff at the Center for Nanophase Materials Sciences at Oak Ridge National Laboratory in Tennessee—

[1] Lux Research, Inc. 2005. *Statement of Findings: Benchmarking U.S. States in Nanotech.* New York: Lux Research, Inc.

the first of the DOE centers to become fully operational—are currently installing equipment and hiring additional researchers.

At this time, the NNI appears well positioned to maintain United States leadership going forward, through both its coordinated interagency approach to planning and implementing the Federal R&D program and its efforts to interact with industry and the public. This approach is clearly outlined in the recently released NNI Strategic Plan, which spells out the goals and priorities for the initiative for the next 5 to 10 years. The NNAP surveyed the TAG to augment our review of this Plan, and we believe it provides an appropriate way to organize and manage the program, and that the goals and priorities outlined in the Plan are likewise appropriate.

There are a number of cautionary notes and minor recommendations contained in our report, which I will detail in a few minutes when I discuss how we can do better, and I would be happy to answer any other questions on items I may not have covered in my testimony. However, overall I think I can safely say that the NNAP endorses current funding and management of the NNI and believes the strategic direction of the program is sound at this point.

Are we addressing societal concerns and potential risks?

The NNAP believes that the societal implications of nanotechnology—including environmental and health effects—must be taken into account simultaneously with the scientific advances being underwritten by the Federal Government. In its review, the Panel found that the NNI does recognize this, and is moving deliberately to identify, prioritize, and address these concerns. The NNI and NNCO are more organized on this front than when the PCAST first began its review of the NNI two years ago. Because, as many members of the Congress and this Committee have rightly pointed out, addressing risks and societal concerns is so important, the NNAP placed special emphasis on this topic, and will continue to do so.

In order to gain insight into environmental, health, and safety issues around nanotechnology, the NNAP convened a panel of experts from Government regulatory agencies, academia, and the private sector. Based on this panel discussion, as well as on information received from the NSET Subcommittee and its TAG, the NNAP believes that potential risks do exist and that the Government is directing appropriate attention and adequate resources to the research that will ensure the protection of the public and the environment. The NNAP is particularly pleased that strong communication exists among the agencies that fund nanotechnology research and those responsible for regulatory decision-making. The pertinent government agencies are devoting more attention and resources toward these issues than most people may realize.

In addition to research into issues related to environmental, health, and safety effects of nanotechnology, the NNI's diverse and growing R&D program is exploring other societal issues such as economic, workforce, and ethical impacts. The NNAP believes that understanding the impact of a new technology on society is vital to ensuring that

development takes place in a responsible manner. The NNAP is pleased with the level of discourse on societal issues and believes these efforts should continue.

In addition, communication with the various stakeholders, including the public, on these topics is an important element of the program. Therefore, we were pleased that the interagency group managing the NNI established a new subgroup to address the topic of public engagement.

One societal issue that I would say has engendered the most lingering concern for the NNAP during this review is one which also affects the broader science and technology enterprise and about which PCAST has previously studied and reported. That is, the health of science education in the U.S. and the projected shortage of a qualified science and technology workforce. The future economic prosperity of the United States will depend on a workforce that both is large enough and has the necessary skills to meet the challenges being posed by global competition. This will be especially important in allowing the United States to maintain its leadership role in nanotechnology and the industries that will use nanotechnology. The NNI has launched a range of education-related programs appropriate for classrooms at all levels and across the country, along with other programs that are aimed at the broader public. While the NNI cannot be expected to solve the Nation's science education problems single-handedly, the NNAP believes that NNI activities can help improve science education and attract more bright young minds into careers in science and engineering. The issue of science education in the U.S. is one about which the PCAST feels strongly, and I would direct you to our previous report, *"Sustaining the Nation's Innovation Ecosystem: Maintaining the Strength of Our Science and Engineering Capabilities"* for more information and for our views on this issue generally.

How can we do better?

This chapter of our report presents NNAP recommendations for how we feel the NNI program can be strengthened and improved. I will describe briefly the areas in which our recommendations are principally focused, and would be happy to answer questions about these and any of the other recommendations in our report.

Technology Transfer: The issue of facilitating the transfer of technology from government labs or universities into the marketplace is a subject that I know this Committee has been interested in and which generates a significant amount of discussion. In the case of nanotechnology, the level of interest and investment across many industrial sectors is growing and will likely outpace Government investment in the United States soon, if it hasn't already. In our report, the NNAP recognizes and applauds current efforts to promote technology transfer, such as ongoing dialogues between the NNI and various industries and recent efforts by research agencies to direct Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) contracts toward nanotechnology projects. However, the NNAP also believes there are additional steps the NNI should take to further communicate with and

establish links to U.S. industry in order to facilitate technology transfer from the lab to the marketplace.

The NNAP calls out two particular areas that could augment the existing suite of activities and enhance commercialization of research results. The first of these is increasing NNI's outreach to the States, which, as previously noted, are directing considerable funding toward nanotechnology projects. The NNAP believes that greater Federal-State interaction can leverage the investments and competencies of both. States, in particular, have a strong interest in and capacity for stimulating economic development and commercial activity.

A notable example of State activity is Albany NanoTech, home to five R&D centers and the College of Nanoscale Sciences and Engineering at the State University of New York (SUNY) Albany. As you heard in testimony by Mr. Michael Fancher at the May 18th hearing that you convened, Albany NanoTech has attracted over $1 billion in private investment and has over 100 partnerships with other universities, federal labs, and industry. Programs in nanoelectronics have led to close relationships with major electronics firms such as IBM, ASML, Tokyo Electron and International Sematech.

Oregon is another state that has developed a nanotechnology initiative and committed state funds to support infrastructure development for Oregon's Nanoscience and Microtechnologies Institute. The University of South Carolina has invested in the creation of the USC NanoCenter to serve as a focal point for the University's nanotechnology research, to foster multidisciplinary research and education efforts, and to promote economic development. South Carolina's NanoCenter has developed a special emphasis on creating dialogue concerning the societal and ethical implications of nanotechnology. These are a few examples of specific state and regional activities. Obviously, there are others, including states like California, Texas and Illinois, all of which are very active in supporting technology clusters to spur economic development.

The NNI has begun to reach out and understand what the states are doing, as evidenced in workshop on Regional, State, and Local Nanotechnology Initiatives held in late 2003. The NNAP encourages more outreach to the States to help leverage the Federal investment. Such efforts would complement those NNI activities already underway with various industrial sectors. The NNAP believes the States perform a vital role in fostering economic development through business assistance programs, tax incentives, and other means. The NNAP believes that practical application of NNI-funded research results, workforce development, and other national benefits will increase with improved Federal-State coordination.

A second, related effort is the development of improved knowledge management of NNI assets. Funding for the NNI to date has resulted in a vast network of assets that should, through proper management, be available to outside researchers and other private interests. The NNAP recommends the NNI focus on improving access to its knowledge assets – including user facilities and instrumentation available to outside researchers, research results, and derivative intellectual property. Through mechanisms such as

publicly available and searchable databases, the NNI can—and should—improve infrastructure utilization and the transfer of technology to the private sector.

While the NNAP agrees that ultimate commercialization of nanotechnology is desirable and to be supported, I do want to emphasize that the Panel feels strongly that the NNI must remain mindful of its primary focus toward developing an understanding, through research and development, of the novel properties that occur at the nanoscale and the ability to control matter at the atomic and molecular level. While we all want the United States to benefit economically from nanotechnology as quickly as possible, it is critically important that the basic intellectual property surrounding nanotechnology be generated and reside within this country. Those who hold this knowledge and who have a workforce prepared to exploit it will "own" commercialization in the future.

Environmental and Health Implications: Picking up on the issues raised in Chapter 3, the NNAP recommends the NNI continue its efforts to understand the possible toxicological effects of nanotechnology and, where harmful human or environmental effects are proven, that the pertinent Federal agencies should promptly regulate accordingly. Nanotechnology products should not be immune from regulation, but such regulation must be based on science and rationality, not perceived fears and irrationality. Judging on where we are today with existing research and regulation, it appears that the public and the environment are adequately protected through existing regulatory authorities. However, the NNAP encourages continued research into possible toxicological effects – particularly in the workplace - and urges Government regulatory agencies to work together to ensure that any regulatory policies that are developed are based on the best available science and are consistent among the agencies. The NNAP recommends coordinating and sharing environmental, health and safety research results internationally to ensure that that efforts are not duplicated unnecessarily and information is shared widely. The NNAP will continue to monitor the development of these issues very closely.

Program Component Area Flexibility: In accordance with the Act, the interagency group that coordinates the NNI has identified seven Program Component Areas (PCAs) that generally follow the broad categories of foundational research being conducted today. The PCAs represent areas in which ongoing and coordinated investment across multiple agencies will be required to support development of the many anticipated applications of nanotechnology. The NNAP recommends that these PCAs be regularly re-examined and adjusted as necessary to track the developments in the nanotechnology R&D field. Today's PCAs should not be viewed as set in stone, and today's organizational choices cannot be allowed to continue indefinitely and thereby to drive the future progression of the program. We cannot know where the state of nanotechnology will be 10 years from now, but we can be fairly certain it will be considerably different than exists today.

Education/Workforce Preparation: A key to realizing the economic benefits of nanotechnology will be the establishment of an infrastructure capable of educating and training an adequate number of researchers, teachers, and technical workers. To

maximize the value of its investment in developing materials and programs for education and worker training, the NNAP felt that better relationships should be established between the NNI and the Departments of Education and Labor. While the science agencies such as the National Science Foundation (NSF) can conduct education research and design excellent programs and materials, ultimately the mission agencies, Education and Labor, must be engaged to disseminate these programs and materials as widely as possible throughout the Nation's education and training systems. The NNAP also felt that the NNI's education focus should be on promoting science fundamentals at K-16 levels, while encouraging the development and incorporation of nanotechnology-related material into science and engineering education. To promote mid-career training for professionals, the NNAP recommends that the NNI partner with and support professional societies and trade associations that have continuing education as a mission.

Other Societal Implications: The NNAP strongly supports continued NNI funding for research aimed at understanding the societal implications of nanotechnology, including ethical, economic, and legal aspects. The NNAP members believe the NNI also must work to inform the public about nanotechnology and seek to understand and address public concerns about this emerging area of technology development. Now more than ever, those who are developing new scientific knowledge and technologies must be aware of the impact their efforts may have on society. Nanotechnology, like biotechnology, has the potential to require individuals, corporations, and governments to make decisions that have ethical, legal, and other societal implications. The NNI must actively engage scholars who represent disciplines that might not have been previously engaged in nanotechnology-related research to address these issues. Moreover, these efforts should be integrated with conventional scientific and engineering research programs so that the people who develop nanotechnology are more fully aware of the societal implications of their work. While the NNAP generally felt that the NNI through its National Nanotechnology Coordination Office (NNCO) has done a good job initiating public outreach and is working to facilitate stakeholder discourse on these subjects, we would encourage continued attention to societal issues into the future.

Other Recommendations / NNAP Report Schedule: Beyond the issues I have highlighted, the NNAP report generally endorses the NNI and recommends continued robust funding to help maintain U.S. leadership. We also suggest increased coordination with other interagency groups and more involvement by agencies not participating in NNI at a level appropriate to their mission, most notably DHS. Finally, there are a few administrative items, such as a recommendation that the NNAP report schedule be adjusted to more adequately complement NNI strategic plan reporting activities. These recommendations and others are more fully described in the report, and I would be happy to respond to any follow-up questions you have.

Conclusion

In conclusion, speaking as a member of the NNAP who has been very closely involved in studying and monitoring developments in nanotechnology over the past several years, and as a an early participant in the semiconductor research industry, I am personally excited about the continual flow of new discoveries and truly revolutionary opportunities made possible by nanotechnology R&D. I believe the NNAP report echoes this enthusiasm and conveys our general support for continuing down the path of robust funding and support for the NNI in order to maintain the U.S. competitive edge in this emerging area. I particularly appreciate the work of this committee and the support in Congress generally for nanotechnology R&D, and I look forward to continued dialogue with you on this important research endeavor.